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1. Conductive Spacecraft Materials Development Program

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Abstract

A jointly planned U.S. Air Force-NASA program has been established to investigate the spacecraft charging phenomenon. The objectives of this program are to provide design criteria, techniques, materials, and test methods to ensure control of absolute and differential charging of spacecraft surfaces. The materials development task of the investigation is the responsibility of and is being directed by the Air Force Materials Laboratory (AFML).

The control of absolute and differential charging of spacecraft cannot be effected without the development of new and improved or modified materials or techniques that will provide electrical continuity over the surface of the spacecraft. The materials' photoemission, secondary emission, thermooptical, physical, and electrical properties in the space vacuum environment both in the presence and absence of electrical stress and ultraviolet, electron, and particulate radiation, are important to the achievement of charge control. The materials must be stable or have predictable response to exposure to the space environment for long periods of time. The materials of interest include conductive polymers, paints, transparent films and coatings as well as fabric coating interweaves. The program initiated by the AFML and related efforts to develop these new or modified materials will be discussed.

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1. INTRODUCTION

A jointly planned U.S. Air Force-NASA interagency interdependency cooperative research and technology program[1] has been established to investigate the synchronous orbit spacecraft charging phenomena. The objectives of this program are to provide design criteria, techniques, test methods, analytical models, environmental data, and materials to ensure the control of absolute and differential charging of spacecraft surfaces for the reduction/elimination of arcing/discharging. The investigation has been divided into a number of concurrent tasks or topics represented by the program topics of the Air Force/NASA Spacecraft Charging Technology Conference; Geosynchronous Environment, Spacecraft Charge Modeling, Materials Characterization, Materials Development, and Design and Test. Responsibility and direction of these tasks have been assigned to various Air Force and NASA laboratories and centers. The materials development task of the investigation is the responsibility of and is being directed by the AFML.

2. BACKGROUND

The exterior surfaces of a synchronous orbit satellite, present a variety of dissimilar material surfaces ranging from polished metals to organic and inorganic dielectrics to the ambient and disturbed, magnetic substorm, environment. A satellite immersed in the synchronous environment will come into electrical equilibrium, developing surface charges of the proper sign and magnitude to reduce the net current between satellite and the environment to zero. A satellite with parts in the sun and parts in the shade can be expected to charge differentially due to the photoemission effects. During periods of eclipse or in the case of three-axis stabilized satellites with sun oriented solar arrays, some surfaces of the spacecraft are never exposed to sunlight. Without the photoemission of electrons to discharge the satellite surfaces, extremely high negative potentials can then appear. The capacitance and resistance between the various parts, as well as the dynamic characteristics of the ambient flux and satellite spin rate, will determine the charging/discharging rates. If adjacent parts or areas of a satellite are charged to be multikilovolt differential, then the electrical stress may be great enough to cause breakdown of arcing between the parts. The resultant arcing/discharging may then give rise to electromagnetic interference generated anomalous behavior or even catastrophic failure in the satellite electronics and related subsystems and/or degradation of the thermal control properties of the surfaces. The latter results in a rise in satellite component temperatures. Since the lifetime requirements of geosynchronous satellites are increasing from the present three to five to seven to ten years, it is necessary to prevent this degradation to ensure satellite lifetime and performance.

Various active and passive techniques have been proposed for the control of the surface potential of a satellite in synchronous orbit in order to reduce or eliminate the charging problems. These range from the use of ion or electron thrusters as on ATS-5 and -6[2,3] and active control of the Jupiter Orbiter probes[4] to the use of electron emitting probes.[5,6] The use of selected materials with high secondary electron emissions have been proposed to help avoid high negative equilibrium potentials.[7] Simple models have been developed for estimating the surface potential of satellites with insulating coatings.[8] However, in all of these cases, strong potential gradients will inevitably exist and the simple models and achievement of an isopotential surface will be achieved only if the entire exterior surface of the satellite is conductive. Therefore, in order to achieve control of the absolute or differential charging of a satellite, the entire exterior surface must be made electrically conductive.

Examination of current and future generation geosynchronous satellites reveals the presence of a relatively small number of exterior materials: transparent dielectric solar cell covers for large surface solar arrays, the backside of the array may be a bare or painted organic, dielectric or metallic material; areas of multilayer thermal insulation, (MLI) blankets, with outer metallized polymeric dielectric layers for the ends, sides, and/or back of much the spacecraft body; flexible, metallized polymeric films or inorganic, fused silica, series emittance coatings or optical solar reflectors (OSR's) for high heat rejection surfaces. Other painted or metallized polymeric dielectric tapes or films are used as shrouds and antenna covers or to wrap booms and other structures. A minimum area of painted or bare metallic surfaces make up the remainder of the exterior thermal control surface. With the exception of the bare metallic surfaces none of these materials are electrically conductive.

In the case of most operational satellites, the control of differential charging below the arc/discharge threshhold will prevent the anomalous and catastrophic behavior previously observed, while on scientific technology satellites the absolute control of surface potential is often necessary in order to accurately define the satellite sheath and plasma environment. The effect of spacecraft surface potential on contamination; that is, the attraction of ionized outgassing organic species, is another consideration and is the subject of a later paper, (Air Force Materials Laboratory ML 12) Spacecraft Charging/Contamination Experiment on SCATHA.[9] The SCATHA SC1, Spacecraft Surface Potential Monitor (SSPM) Experiment[10] will evaluate the surface potential of a variety of selected satellite thermal control materials exposed to the synchronous space environment.

The Air Force SCATHA Satellite[11] scheduled for launch in mid 1978 will study the spacecraft charging phenomena and measure the substorm generated environmental parameters. The engineering experiments on SCATHA will measure the materials response to environmental charging and the effects of charging on materials contamination. The data obtained will be used to substantiate and correlate with laboratory in situ simulation measurements and to guide materials development. However, these data will not be available in a time frame to effect the material selection for a number of operational Air Force satellites or the immediate material development efforts.

The time required for the development, evaluation and flight qualification of a new spacecraft thermal control material acceptable to the spacecraft thermal designers and engineers is estimated to be from three to five or more years. In particular, this is true, for any material expected to perform for seven to ten years or more in the space environment.

3. MATERIALS DEVELOPMENT PROGRAM

Based upon the above background it is obvious that the control of absolute and differential charging of spacecraft cannot be effected without the development of new and improved or modified materials or techniques which will provide electrical continuity over the surface of the spacecraft. A coordinated Air Force/NASA program was initiated by the AFML to develop these new or modified materials. The materials of interest include conductive polymers, paints, transparent films and coatings as well as fabric interweaves. The program roadmap is indicated in Figure 1. In order to meet the near term satellite conductive materials requirement the approach has been to develop materials modifications and techniques which can be applied to current state-of-the-art thermal control materials which can be integrated directly into the current and near term generation of satellites without a long three to five years or more period necessary to space qualify new materials. At the same time promising approaches for the development of new and novel materials will be identified for later research and development.

3.1 Conductive Fabric Coatings

The concept of silica fabric type thermal control coatings was developed under AF sponsorship. These materials are extremely space stable, contamination free materials and are candidates for any thermal control applications requiring coatings with low solar absorptance to emittance ratios such as white paints, as the outer layers of multi layer blankets or on the back of solar array panels

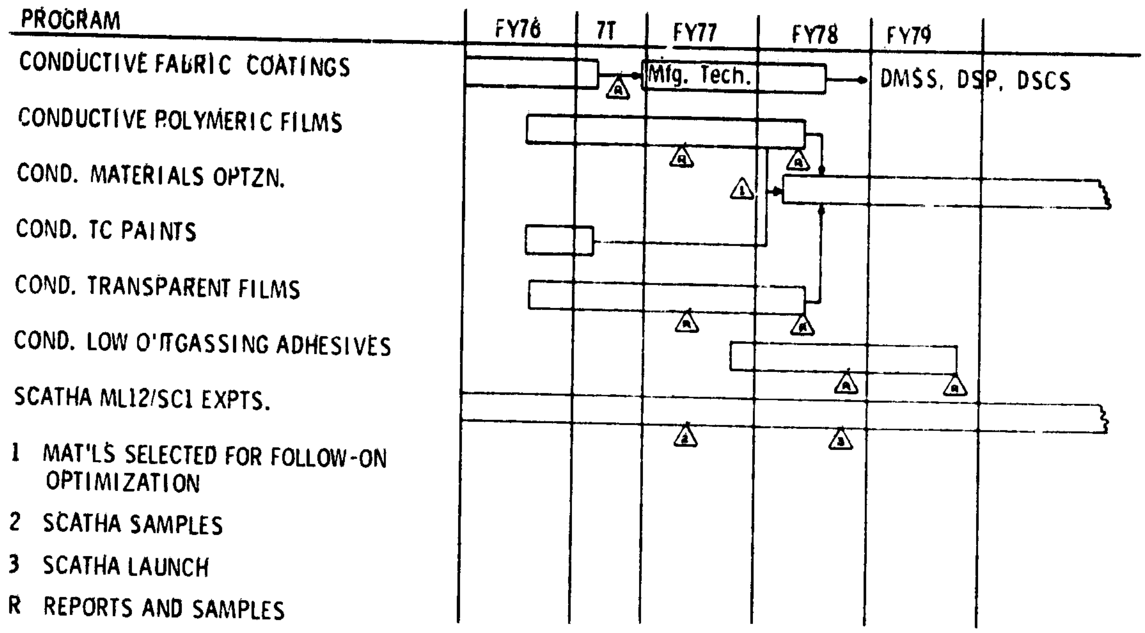

Figure 1. Combined AFSC/NASA Conductive Spacecraft Materials Development Roadmap

A contractual program to develop conductive interweaves of metallic aluminum, stainless steel, or other conductive filaments such as carbon, and space stable, silica fabric type thermal control coatings was initiated. Alternate approaches include the use of sewn in conductive yarns or conductively coated silica yarns. As reported elsewhere in this meeting[12, 13] it has been found since this interweave program was initiated that the basic silica fabric when applied as the outer layer of a thermal blanket does not arc/discharge. The conductive interweaves will ensure a minimum distance from any area of the coating to a stable ground conductor limiting the area or total charge available for discharge. The conductor will have adequate capacity to conduct any discharge to ground without conductor loss by heating or sputtering such as might occur with thin vacuum deposited conductors.

A program to develop the manufacturing technology to prepare an optimized fabric in the proper weight and physically desirable widths for satellite use including cleaning, handling, shipping, and other techniques has just recently been initiated. The materials developed have been proposed for use in a number of current and future satellite thermal control applications.

3.2 Conductive Polymeric Films

The development of techniques and modifications which will reduce or prevent the accumulation of a spacecraft charge on the surfaces of FEP Teflon or Kapton used in thermal blankets and tapes and films is being pursued under contract at General Electric. Approaches include materials modifications and conductive metallic or oxide grids and coatings prepared by vacuum deposition or photo resistant techniques as well as the development of stable grounding techniques. Details will be discussed in a later paper.[14]

3.3 Conductive Thermal Control Paints

Potential routes for the development of stable white paint type thermal control coatings have been investigated under a contractual program at IITRI and will be reported on in a later paper.[15] Approaches included the investigation of conductive and nonconductive polymeric organic (quaternary ammonium polymers, polyvinylcarbazole) and inorganic (alkaline silicate) binders applied separately or in conjunction with conductive pigments, fiber or filaments.

The development of conductive, space stable, (five to ten years) white thermal control coating pigments is a very challenging technical problem. The techniques used to impart conductivity such as doping or non-stoichiometry being contrary to the factors necessary to impart long term space stability.

Conductive inorganic based thermal control paints have been developed in-house at NASA in support of the ISEE program.[16] Recent laboratory investigations[12] under simulated synchronous orbit, substorm conditions indicate that the thermal control paints charge but do not arc/discharge. The conductivity of the paints tend to increase with surface potential bleeding the charge imposed by the electron flux to ground. The conductive paints do not charge conducting the charge to ground. Conductive black thermal control coatings are available.

3.4 Conductive Transparent Films

Research and development of low cost conductive transparent coatings for application to both organic and inorganic series emittance coatings or optical solar reflectors (OSR's) and solar cell covers is being conducted under a contractual program at General Electric. Approaches include the deposition or formation of transparent and metallic conductive grids and transparent inorganic coatings by vacuum, electrochemical and mechanical techniques. The affect of the coatings or grids on the thermooptical properties, energy conversion, and long term stability of the state-of-the-art materials will be evaluated. The development and use of conductive glasses for the covers are also being evaluated. Grounding techniques will be developed.

Conductively coated solar cell covers and OSR's are commercially available, but the prices are prohibitive if one envisions a large solar array of many tens of thousands of solar cells.

3.5 Materials Optimization

Materials will be selected for further development and optimization based upon the results of the initial programs. Samples of the most promising materials will be evaluated as potential samples for inclusion in the SCATHA and other space flight experiments.

3.6 Conductive Low Outgassing Adhesives

A program for the developm of conductive, low outgassing/low contamination adhesives will be initiated late in the current fiscal year. The use of conductive adhesives to apply metallized inorganic and organic OSR's has been shown to reduce the contamination released from the adhesive layer as well as the loss of the vapor deposited metallized mirror layers due to arcing and thereby enhances the long term optical performance of these materials. Similar enhancement of long term optical properties due to reduced contamination is expected.

4. MATERIALS CHARACTERIZATION

The engineering properties beyond the initial screening evaluations of the materials developed under the above programs will be evaluated in the synchronous space environmental simulation facilities developed by the NASA/Lewis Research Center as a part of the cooperative AF/NASA program. The material's photoemission, secondary emission, thermooptical, physical and electrical properties in the vacuum environment both in the presence and absence of electrical stress and ultraviolet, electron, and particulate radiation are important to the achievement of charge control. A literature search[17] on the dielectric properties and electron interaction phenomena related to spacecraft charging has been conducted by personnel of the Rome Air Development Center (formerly assigned to Air Force Cambridge Research Laboratory). The continuing role of this research group in the measurement of the classical electrical, thermal, and optical properties, as well as the basic physical structure of the materials developed is not clear.

Studies of the photoconductivity effects of selected spacecraft materials are being pursued by Nanevicz and coworkers at Stanford Research Institute under a NASA sponsored program.[18, 19]

5. CONCLUSIONS

A coordinated, joint U.S. Air Force-NASA program for the development of conductive spacecraft materials has been initiated. This program is part of a total coördinated, interdependent program to investigate the spacecraft charging phenomena and to provide design criteria, techniques, materials, and test methods to ensure the control of absolute and differential charging of spacecraft surfaces.

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